NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

JAN 6 1993

Reply to Attn of: SZD

TO: Distribution

FROM: S/Associate Administrator for Space Science and Applications

SUBJECT: Astro-D Prelaunch Mission Operation Report (MOR)

The Prelaunch Mission Operation Report for the Astro-D mission is enclosed for your information.

Astro-D is a Japanese-led program involving the United States as a participating partner. The Japanese Institute of Space and Astronautical Science (ISAS) provides overall program management, the launch vehicle, the spacecraft, and two Gas Scintillation Imaging System detectors. NASA is providing four nested, thin-foil, grazing-incidence telescope mirrors and two X-ray charged-coupled device solid-state detectors. NASA also provides telemetry tracking support using Deep Space Network ground stations.

In return for its scientific instrument contribution, the U.S. will receive 15 percent of the observing time and will share an additional 25 percent for collaborative U.S./Japan scientific investigations. Launch is scheduled for mid-February 1993 from the ISAS launch center near Kagoshima in southern Japan.

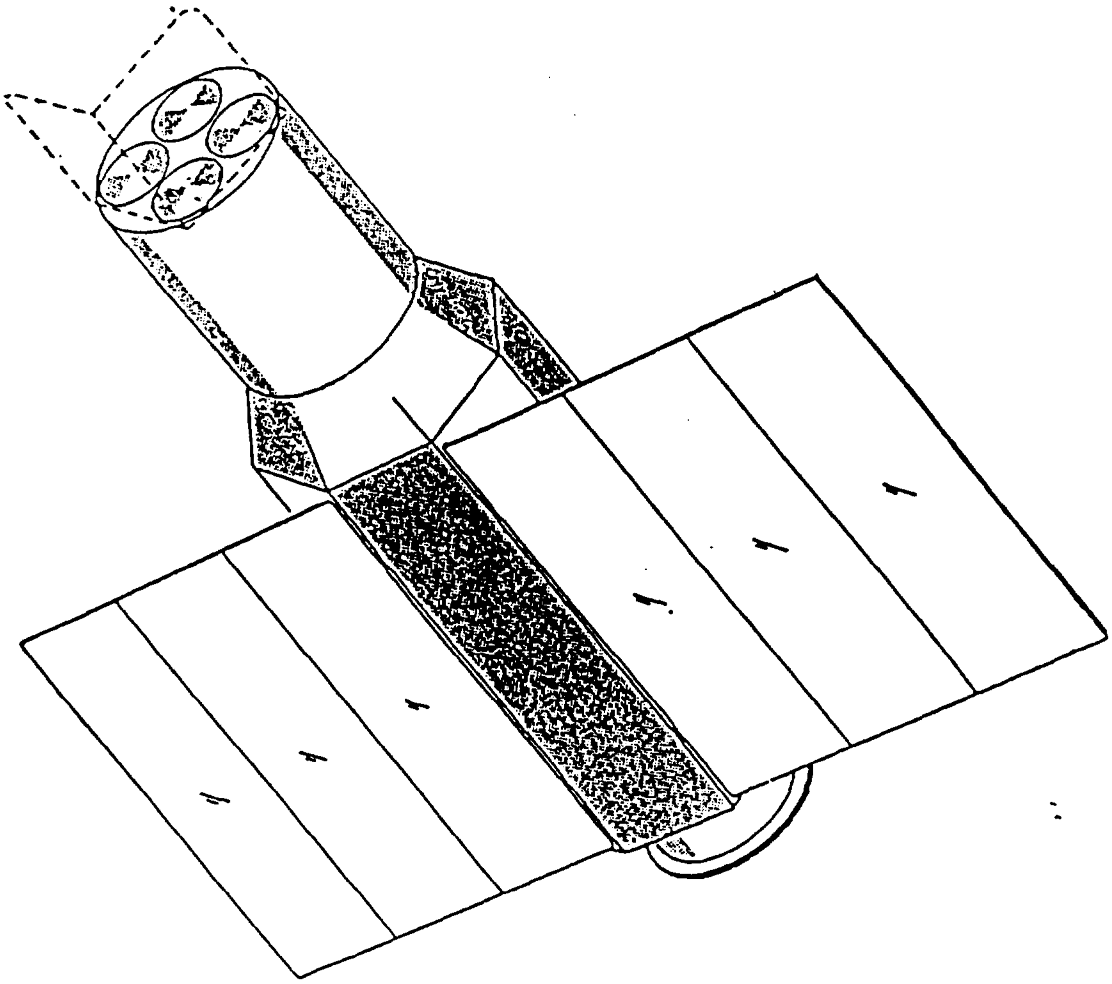
This MOR: (a) describes the NASA objectives for the Astro-D mission; (b) provides brief descriptions of the spacecraft and its scientific instruments; (c) provides a chronology of launch and deployment; and (d) describes the ground operation elements that support the mission.

L. A. Fisk

Enclosure

Mission Operation Report

Office of Space Science and Applications
Report No. S-689-93-01



ASTRO-D

FOREWORD

MISSION OPERATION REPORTS are published for the use of NASA Senior Management, as required by NASA Headquarters Management Instruction HQMI 8610.1C, effective November 26, 1991. The purpose of these reports is to provide a documentation system to establish critical discriminators selected in advance to measure mission accomplishment, provide a formal written assessment of mission accomplishment, and provide an accountability of technical achievement.

Pre launch reports are prepared and issued for each flight project just prior to launch. Following launch, updating (post launch) reports are issued to provide mission status and progress in meeting mission objectives.

Primary distribution of these reports is intended for personnel having program/project management responsibilities.

PREPARED BY:
Astrophysics Division
Office of Space Science and Applications
NASA Headquarters

PUBLISHED AND DISTRIBUTED BY:
Executive Support Office (Code JA)
Office of Management Systems and Facilities
NASA Headquarters

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

Å	Angstrom Units
arcmin	Arc Minutes
arcsec	Arc Seconds
BBXRT	Broad Band X-ray Telescope
C	Degrees Celsius
CCD	Charge Coupled Device
cm^2	Square Centimeters
diam	Diameter
E	East
DSN	Deep Space Network
GIS	Gas Scintillation Imaging System
GSFC	Goddard Space Flight Center
HEAO	High Energy Astrophysical Observatory
HEASARC	High Energy Astrophysics Science Archive Research Center
HPR	Half Power Radius
HV	High Voltage
IGSPC	Imaging Gas Scintillation Proportional Counter
ISAS	Institute of Space and Astronautical Science
JPL	Jet Propulsion Laboratory
kbps, KBPS	Kilobits Per Second
KeV	Kilo-electron Volts
kg	Kilograms
km	Kilometers
Lat.	Latitude
Long.	Longitude
m	Meters
μ	Microns
mm	Millimeters
Mbit	Megabit
min	Minutes
MIT	Massachusetts Institute of Technology
N	North
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NASDA	National Space Development Agency
OSSA	Office of Space Science and Applications
PMT	Photo Multiplier Tube
RBM	Radiation Burst Monitor
sec	Seconds
SIS	Solid State Imaging System
SSOC	Sagamihara Space Operation Center
W	Watts

OVERVIEW

The Japanese Institute of Space and Astronautical Science (ISAS) and the United States National Aeronautics and Space Administration (NASA) have agreed to undertake a cooperative mission utilizing the Japanese Astronomy Satellite Astro-D to be launched on a Japanese M-3SII expendable launch vehicle.

The Astro-D will provide exceptional capabilities for the study of high-energy astrophysical phenomena. The science payload consists of four conical-mirror X-ray telescopes, each with a designated detector. Two of the detectors are gas scintillation counters and two are Charge Coupled Device (CCD) detectors. The combined mirror and detector system will have spatial resolution comparable to the Imaging Proportional Counter of the Einstein Observatory, the ability to measure the surface brightness of the cosmic X-ray background, and spatial resolution at least twice as good as that of the HEAO-2 A-2 proportional counters. Each telescope provides a large effective collecting area that is achieved by the nesting of 119 concentric, thin-foil, gold-plated grazing-incidence mirrors that direct the incoming X-rays to a focal-plane detector.

The intent of Astro-D is to examine a large variety of X-ray sources with moderate spatial resolution and spectral resolution covering the 0.3 to 12 keV band with emphasis on the iron K band. Spectroscopy in the iron band is a high priority objective due to the abundance and richness of relevant features in the spectra of many types of X-ray sources. The spectral coverage of Astro-D also includes spectral features of other elements such as sulfur and silicon, and is sufficiently broad to determine the shape of the underlying continuum. Astro-D has sufficient imaging capability to study the structure of extended sources such as clusters of galaxies and supernova remnants. The spatial resolution is adequate to isolate and study sources nearly as weak as those found in the deep survey of the Einstein Observatory. Still weaker sources can be characterized by examining fluctuations in the cosmic X-ray background.

The Astro-D spacecraft was fabricated by ISAS with four conical X-ray mirrors provided by the NASA GSFC. Two imaging gas proportional counters were provided by ISAS, and two solid state detectors were developed by the Massachusetts Institute of Technology (MIT) and provided by the NASA. Astro-D will be placed in a circular near-Earth orbit of approximately 550 km with an inclination of 31 degrees by the M-3SII launch vehicle. All command and mission control of the Astro-D satellite will be provided by ISAS. NASA will provide routine S-band telemetry data acquisition and recording by appropriate Deep Space Network stations during the Mission.

NASA OBJECTIVES FOR ASTRO-D MISSION

The Astro-D mission is a Japanese program involving the United States as a participating partner. The Japanese Institute of Space and Astronautical Science (ISAS) provides overall program management, the launch vehicle, the spacecraft, the x-ray telescope structure, and two focal plane instruments, Imaging Gas Scintillation Proportional Counters. In cooperation with ISAS, NASA is providing four conical foil x-ray mirror assembles and two X-ray CCD Cameras. NASA also provides tracking support using the Deep Space Network (DSN) ground stations.

Astro-D will provide x-ray spectroscopy measurements of cosmic plasmas. X-rays originate in the most energetic activities in the universe and from the hot gases that often result from energetic events. The spectroscopic precision of Astro-D will enable studies of the elemental composition of cosmic plasmas and about the physics of violent universe. The primary objectives of the Astro-D mission are:

* To examine a variety of x-ray sources with moderate spatial and spectral resolution at energies between 1 to 12 keV, with particular emphasis on the iron K band near 6 keV.

* To study the structure of extended sources such as clusters of galaxies and supernova remnants.

* To determine temperatures and elemental abundances in astrophysical sources through the measurement of spectral features.

NASA's objectives for the Astro-D mission will be accomplished by :

* Making pointed observations of astrophysical sources with Astro-D's complement of co-aligned telescopes.

* Acquiring the scientific data using the DSN and the ISAS ground station.

* Making data form Astro-D observations available to U.S. Astro-D team members and U.S. Guest Observers in a timely manner and providing adequate support to their data analysis requirements.

NASA OBJECTIVES FOR ASTRO-D MISSION

CONCURRENCES:

Alan Bunner

SZ/Alan N. Bunner
Program Scientist

21 Dec. 1992
Date

SZ/John Lintott
Program Manager

12/21/92
Date

George P. Newton

SZ/George Newton
Acting Director, Astrophysics Division

12/21/92
Date

OSSA APPROVAL:

L. A. Fisk

L. A. Fisk
Associate Administrator for
Space Science and Applications

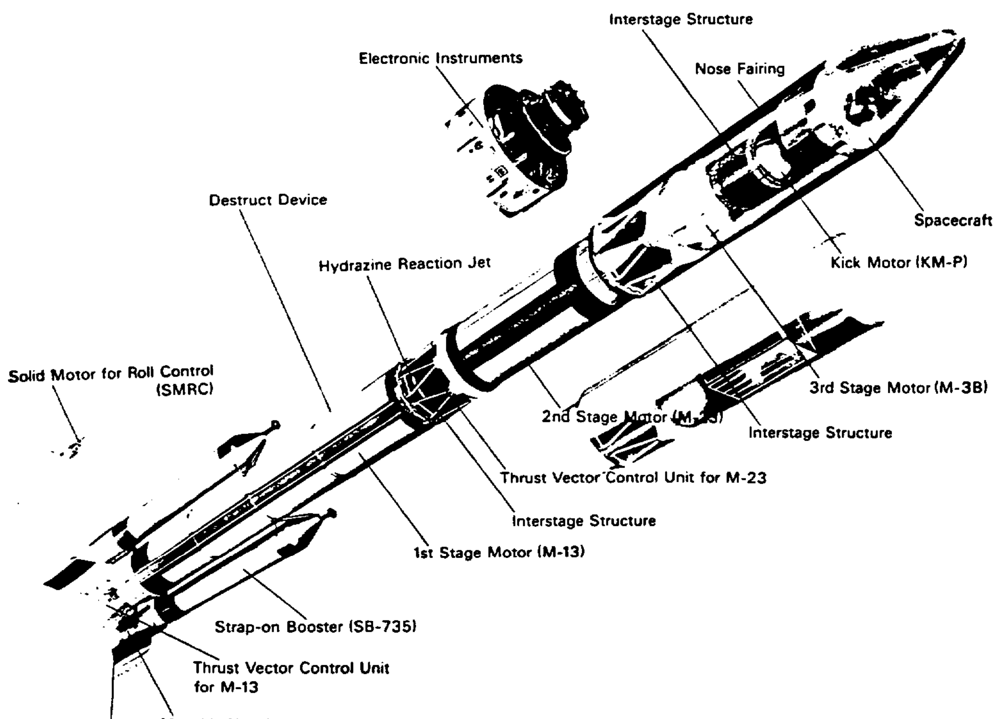
1/6/93
Date

MISSION SEQUENCE

Vehicle and Launch Site

Astro-D will be launched by an ISAS M-3SII launch vehicle from the Kagoshima Space Center in southern Japan into a 550 km altitude, 31° inclination circular orbit. Nominal orbital period is 95.6 minutes.

The M-3SII is a solid propellant, three-stage booster system with an optional fourth stage kick motor. This fourth stage motor is not required for Astro-D. Previous M-3SII launches have included SAKIGAKE (Pioneer) in January, 1985; SUISEI (Comet) in August, 1985; GINGA (Galaxy) in February, 1987; AKEBONO (Dawn) in February, 1989; and YOHKOH (Solar-A) in August, 1991. A cutaway view of the M-3SII is provided by Figure 1 which also includes a performance table showing the characteristics of the various stages including the first stage strap-on boosters.



M-3SII-2 (SUISEI) Performance

	SOB	1st Stage	2nd Stage	3rd Stage	4th Stage
Designation	SB-735	M-13	M-23	M-3B	KM-P
Total Weight (ton)	62.0	52.0	17.3	4.20	0.61
Stage Weight (ton)	10.0	34.7	13.1	3.59	0.47
Propellant Weight (ton)	8.0	27.1	10.4	3.28	0.42
Average Thrust (ton)	67	129	53.4	13.5	3.3

Figure 1. Cutaway View of the M-3SII with Performance/Weight Table

Launch Sequence

The exact launch sequence is not yet available but is expected to be similar to that of the YOHKOH mission with separation of the strap-on boosters occurring 40 seconds after liftoff, first stage separation at 84 seconds, ignition of the second stage at 86 seconds, jettison of the nose fairing at 155 seconds, and separation of the second stage at 240 seconds.

Stage III, with the Astro-D spacecraft still attached, will coast to operational altitude, at which time stage III will be ignited. The time between stage II-III separation and the ignition of stage III for orbit circularization is expected to be approximately 7 minutes at which time stage III and the Astro-D spacecraft will be at the desired altitude of 550 km.

Prior to the ignition of the third stage motor, the spacecraft is spun up to a nominal spin rate of about two revolutions per second. The spacecraft retains this spin rate until the deployment of a set of yo-yo masses whose cables are wound around the spacecraft body.

Orbital Operations

The Astro-D mission will consist of two phases: 1) performance verification phase (expected to last approximately eight months), and 2) a Guest Observer Program. The primary purpose of the first phase is instrument check-out, calibration, software check-out and preparation for a continuing scientific program with a well-characterized system. No guest investigator or visiting investigator program is planned for this period. All detector data from this phase will be made available to the Astro-D team scientists from Japan and the United States.

Upon completion of the performance verification phase, Astro-D will be dedicated to a guest observer program for so long as the satellite is operational.

SCIENCE INSTRUMENTS

System Description

Astro-D is the first "high energy imaging and spectroscopy" mission covering a wide energy range exceeding 10 keV. The main features of the Astro-D science instruments are given in Table 1. The imaging resolution of Astro-D is comparable to that of the Imaging Proportional Counter of the Einstein Observatory, but the X-ray collecting power, energy range and energy resolution are far superior. The satellite will carry four instruments: two X-ray telescopes with CCD camera detectors and two X-ray telescopes with gas scintillation proportional counters.

High Throughput over a Wide Energy Range	
• 4 sets of thin-foil conical mirrors	
• Effective Area:	≈ 1300 cm^2 in < 2 keV
	≈ 600 cm^2 in 6-7 keV
• Focal Length:	3.5 m
• Image Size:	≈ 1 mm HPR (≈ 1 arcmin)
Imaging Capability	
• Focal Plan Instruments: 4 detectors	
• 2 Imaging Gas Scintillation Proportional Counters (IGSPC)	
• 2 X-ray CCD Cameras	
• Point Source Resolution: < 1 arcmin	
Energy Resolution	
• ≤ 8% (5.9 keV) with IGSPC	
• ≤ 2% (5.9 keV) with CCD's (at ≈ -70°C)	

Table 1. Main Features of Astro-D Science Payload

X-ray Telescopes

The X-ray telescopes (XRT) were developed by ISAS utilizing four sets of multi-nested thin-foil conical reflectors in approximate Wolter-I optics provided by the NASA GSFC. One of the mirror assemblies is shown in Figure 2. The mirror technology provides a large throughput through high energies. The effective area will be greater than 1000 cm^2 below 2 keV and greater than 500 cm^2 around 6-7 keV. A comparison of the effective area with previously flown spacecraft is shown in Figure 3. The process by which the mirror foils

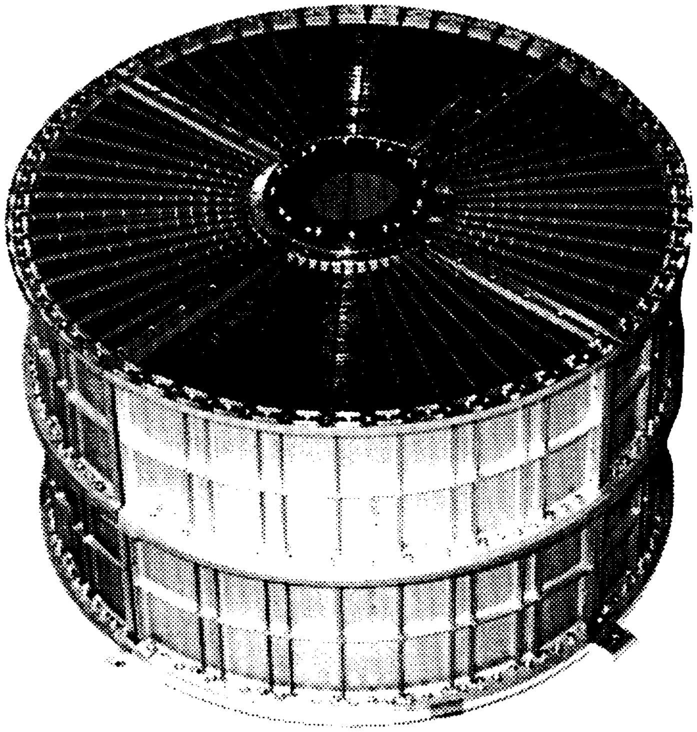


Figure 2. Thin Foil X-Ray Telescope Mirror

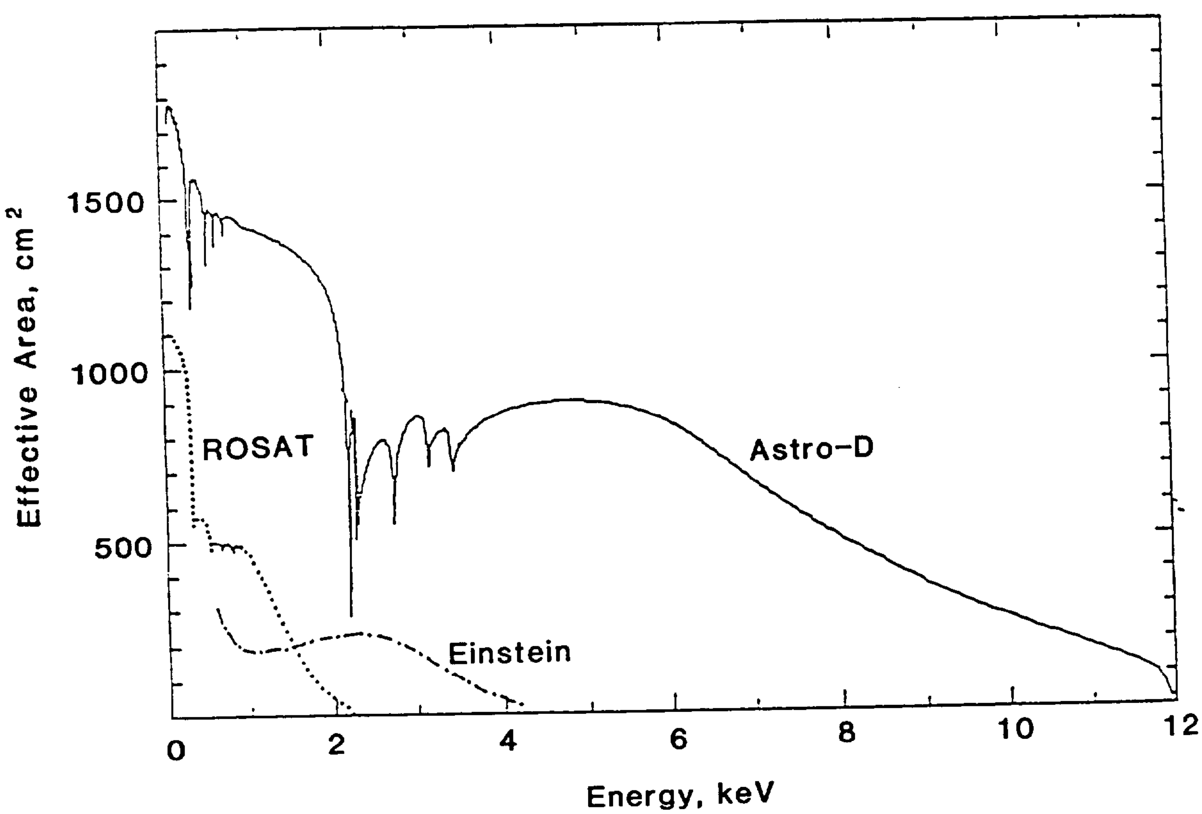


Figure 3. Comparison of Effective Area for X-Ray Payloads

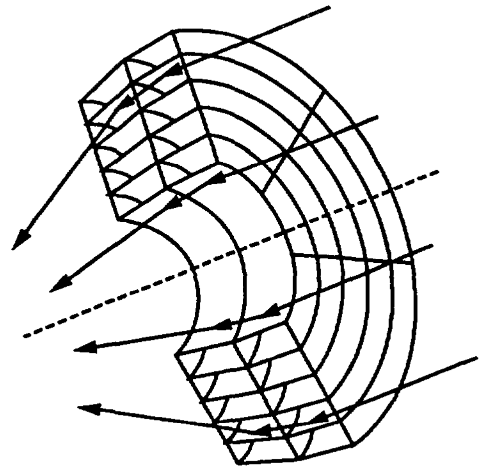


Figure 4. Focussing of Incoming X-Rays

collect X-rays and direct them to the detectors is shown schematically in Figure 4. The properties of each Astro-D mirror assembly are presented in Table 2. The Astro-D mirrors are similar to the GSFC-developed units that were used on Broad Band X-ray Telescope (BBXRT). BBXRT, however had a mission life of only a few days during its flight on the Space Shuttle; the Astro-D mission life should be a minimum of two years.

Size, OD (ID), cm	34 (12)
Weight, kg	9.6
Focal Length, cm	350
Geometric Area, cm^2	558
Grazing Angle Range, degrees	.242-.695
Plate Scale, arcmin/min	.98
Number of Reflectors	119
Reflector Thickness, mm	.127
Reflector Width, mm	101.6
Lacquer Thickness, μ	≈ 10
Gold Thickness, Å	≈ 500
Instrinsic Blur, arcsec dia	≈ 25

Table 2. Properties of Astro-D Mirror Assembly

Solid State Imaging System (SIS)

The SIS consists of two identical independent CCD Camera systems (Figures 5 and 6) which have been developed by the Massachusetts Institute of Technology (MIT). Each module has a hybrid CCD at the focus of a grazing incidence thin-foil telescope. The detector for the SIS is a 840x844 hybrid CCD. Each module has its own signal processing chain with the interface between the analog and digital electronics being digital. Analog signal processing electronics are provided by MIT, while the digital processing electronics are provided by ISAS. The SIS cameras include a thermoelectric cooler to maintain the CCD at -55° C.

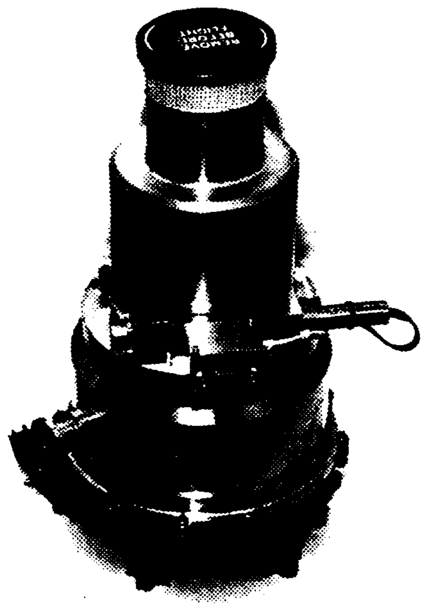


Figure 5. Photograph of SIS Camera System

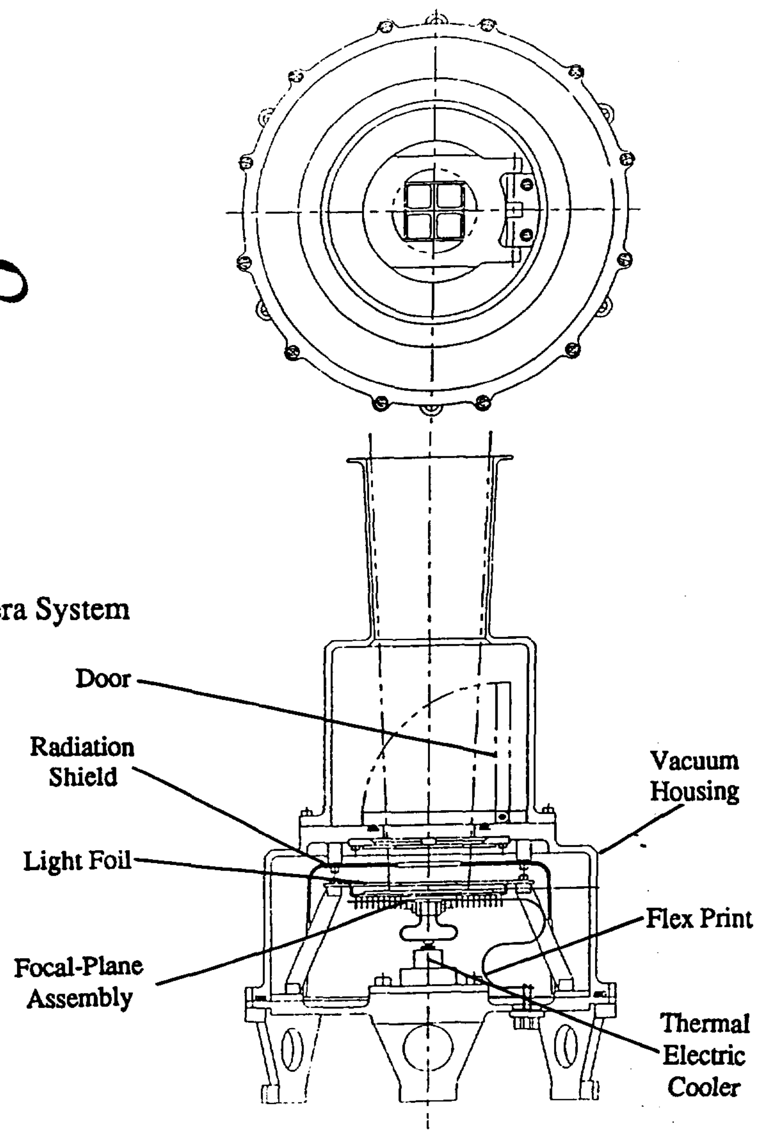


Figure 6. SIS CCD Camera System

Gas Scintillation Imaging System (GIS)

The GIS (Figures 7 and 8) consists of two Imaging Gas Scintillation Proportional Counters (IGSPC) that have been developed by ISAS. The IGSPC comprises a gas cell, a position-sensitive phototube, and front-end electronics. Each IGSPC is contained in a housing that is located on the optical axis of one of the 3.5 m focal length X-ray reflective mirrors. The GIS top section is a hood, which prevents background X-rays and particles entering from outside of the field of view of GIS in the mirror direction. The middle section accommodates the gas cell and the phototube, and the bottom section holds the front end electronics. The signal of the IGSPC is first processed in the front-end electronics and then analyzed in the main electronics of an on-board GIS data system.

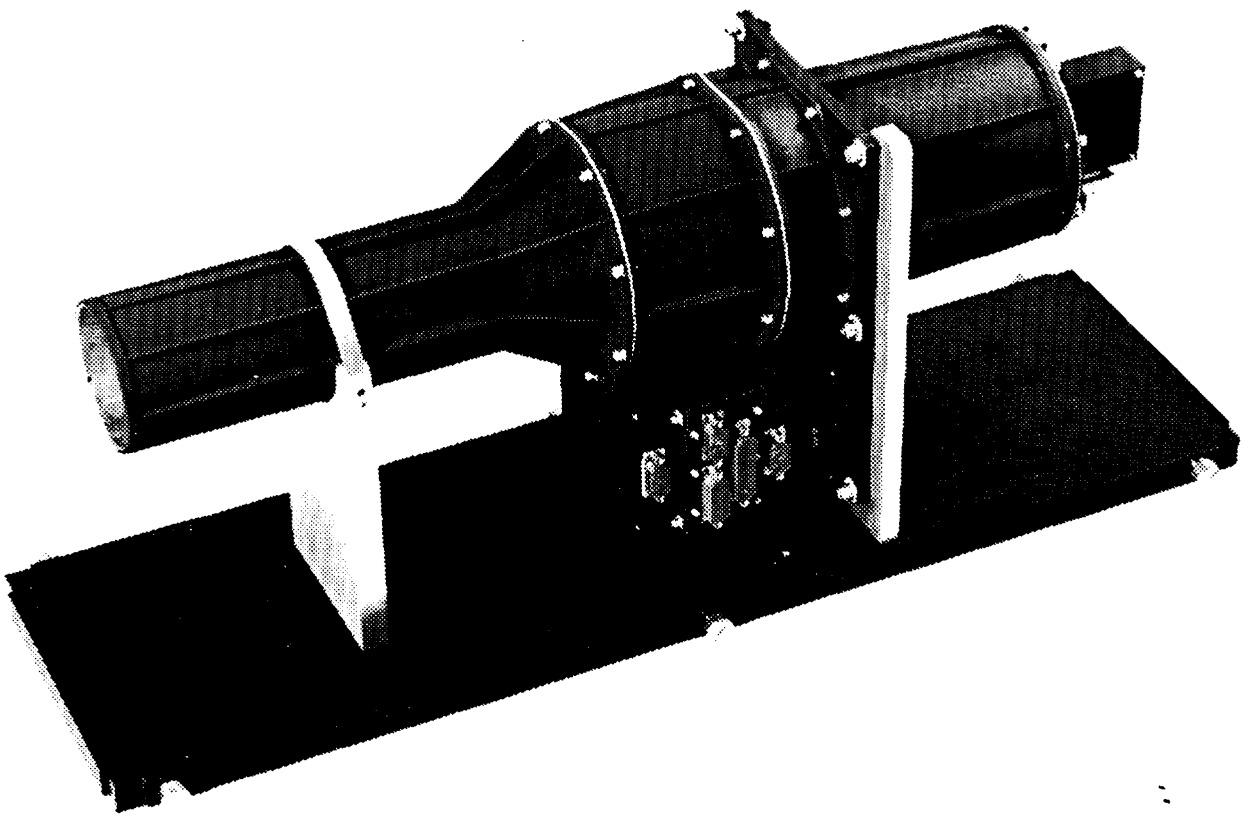


Figure 7. Photograph of GIS

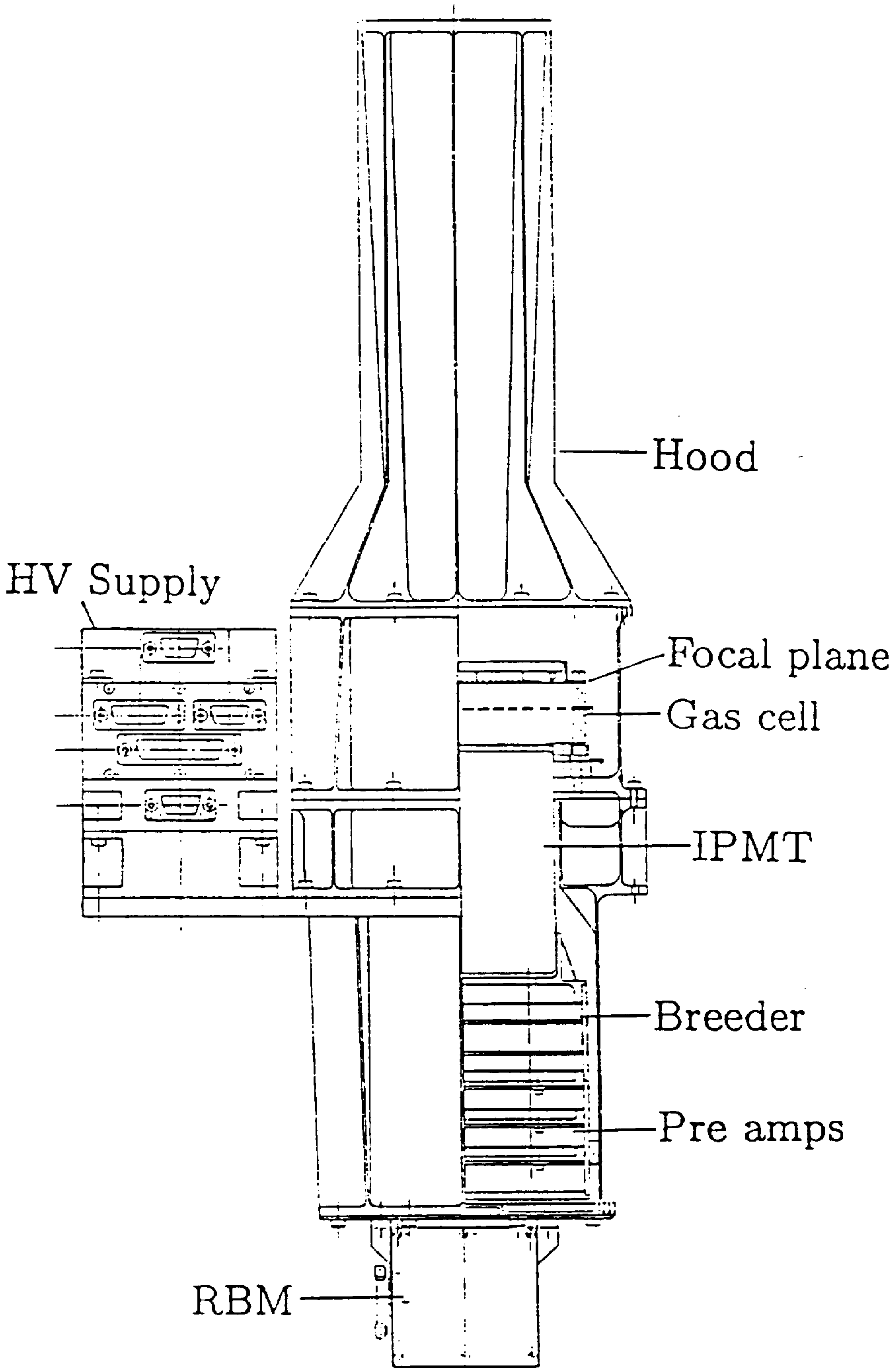


Figure 8. Focal-Plane Assembly of GIS Detector

Comparison of Astro-D Detectors

The characteristics and expected performance of the SIS and GIS detectors is compared in Table 3. The SIS provide Astro-D with high spectral resolution capability and 2% energy resolution compared to 8% for the GIS. The GIS provides better detection efficiency and better time resolution for high energy protons and a larger field of view.

Detector Type	CCD	IGSPC
Developer	NASA/MIT	ISAS
Energy Range	0.3 to 10 keV	0.7 to 12 keV
Spectral Resolution	2 %	8 %
Field of View	22 x 22 arcminutes	30 arcminute diam.
Spatial Resolution	2.9 arcminutes	2.9 arcminutes
Time Resolution	1 - 10 seconds	61 microseconds
Detector Length	303 mm	580 mm
Detector Diameter	165 mm	150 mm

Table 3. Comparison of CCD and IGSPC Detectors

SPACECRAFT DESCRIPTION

The ISAS-provided, 420 kg Astro-D spacecraft will carry four scientific instruments: two X-ray telescopes with CCD camera detectors and two X-ray telescopes with imaging gas scintillation proportional counters. The spacecraft is pictured in its flight configuration in Figure 9.

The design of the spacecraft posed unique challenges for ISAS which has been responsible for its development. To contain the 3.5 meter focal length required for the optics system of the telescopes, the spacecraft needed to be at least 4 meters in length. This dimension was, however, too great to be accommodated by the nose fairing of the M-3SII launch vehicle. To deal with this situation, the ISAS developed a unique carbon fiber extendible optical bench which telescopes down to under 3 meters for launch and then extends to 4 meters when the spacecraft is in orbit. This structure is illustrated in Figure 10.

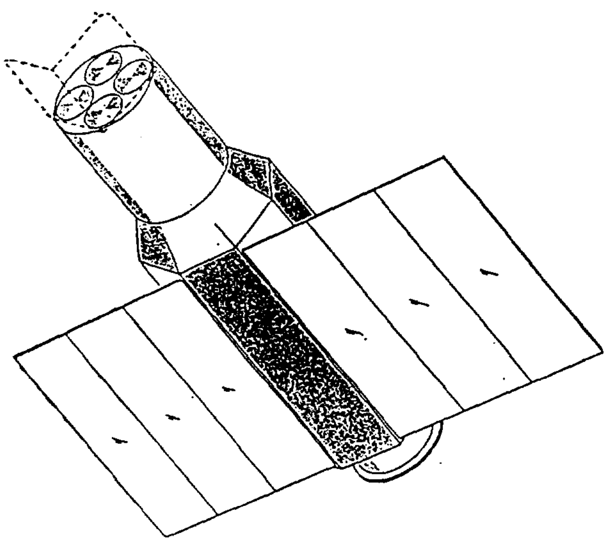


Figure 9. Astro-D Spacecraft

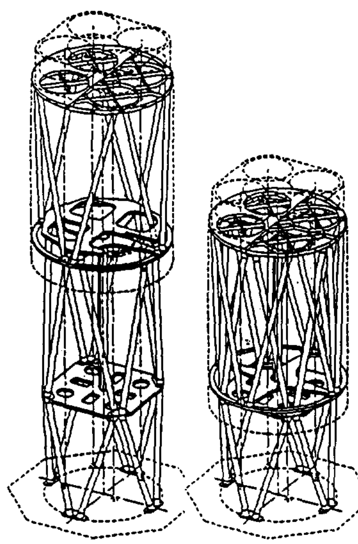


Figure 10. Extendible Optical Bench

A summary of spacecraft and mission characteristics is provided in Table 4. Power is obtained from a six-panel solar array which, in Figure 11, is shown partially deployed during spacecraft testing. X-ray measurements are carried out with a pointing accuracy of better than one arc minute. Science and engineering data are transmitted real time (at 32 kbps) or stored on the spacecraft in a 134 megabit bubble memory for later transmittal to the ground (at 262 kbps). The primary telemetry receiving station is located at the Kagoshima Space Center which also provides operational commands to the spacecraft.

Launch:	Launch vehicle:	M-3SII, 3-stage solid fuel vehicle
	Launch site:	Kagoshima Space Center, Japan
	Launch date:	February 1993
	Mission lifetime:	2 years Primary Mission 2 years Extended Mission
Orbit:	Altitude:	550 km, circular
	Inclination:	31 degrees
	Period:	95.6 minutes
Spacecraft:	Size:	1.2m (diam.) x 4.0m (after extension)
	Weight:	420 kg.
	Power:	200 W
	Data recorder:	134 Mbit bubble memory
	Telemetry:	32 KBPS (real time) 262 KBPS (stored time)
Attitude control:	Stabilization:	3-axis with a bias-momentum wheel
	Pointing accuracy:	< 1 arcmin
	Stability:	< 0.2 arcmin/32 sec.
	Determination accuracy:	< 0.3 arcmin
Ground Stations:	Kagoshima Space Center	
	Contact time:	5 orbits/day (out of 15), no Sunday operation
	Contact duration:	12 minutes/orbit
	NASA Deep Space Network: Uses Madrid, Canberra, and Goldstone to obtain up to four additional contacts per day during primary mission (two/day during extended mission).	

Table 4. Astro-D Spacecraft and Mission Characteristics

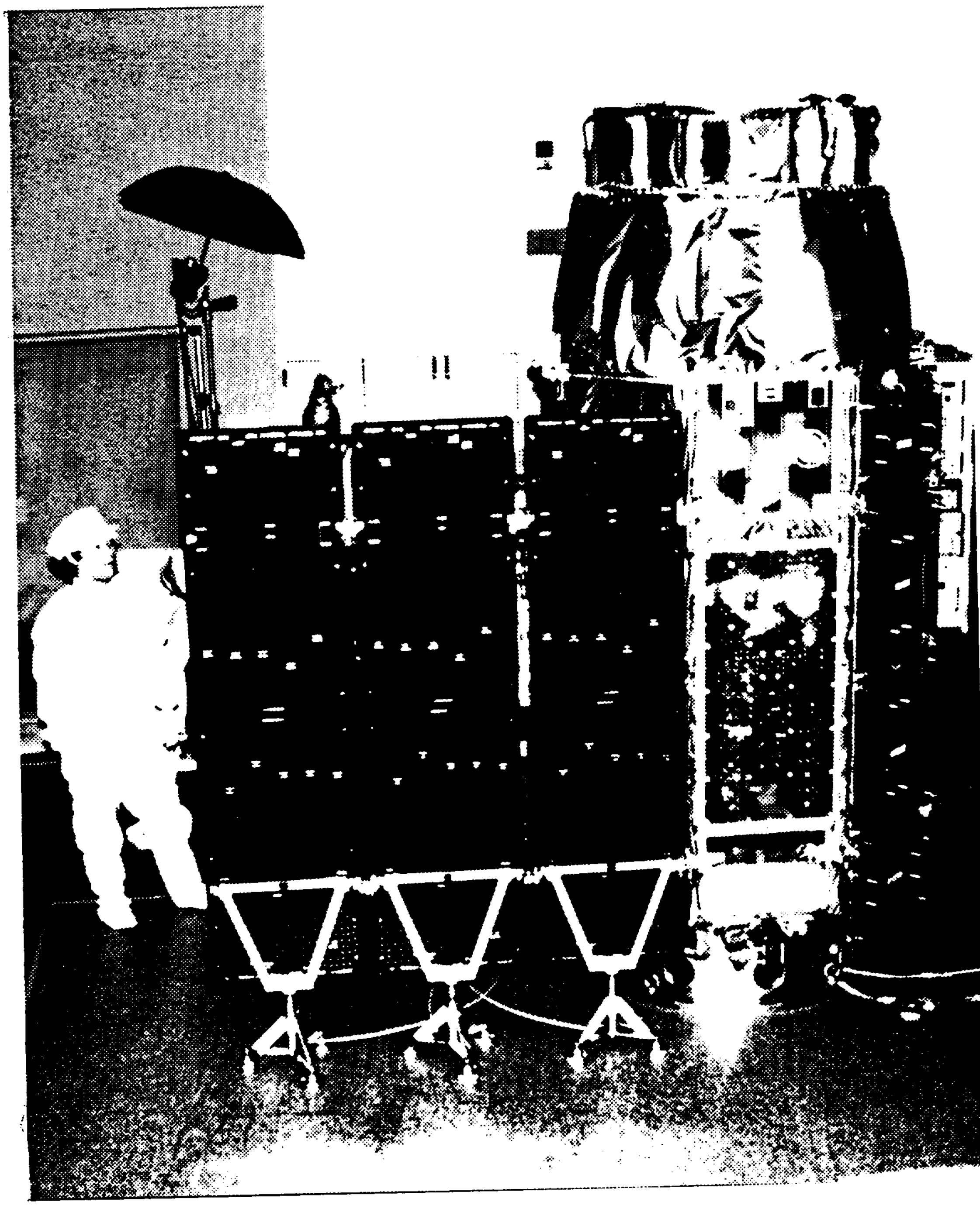


Figure 11. Spacecraft with Partially Deployed Solar Array

MISSION SUPPORT

Mission Control

Mission control is performed at the ISAS Kagoshima Space Center which provides the facilities for spacecraft command and telemetry. The Sagamihara Space Operation Center (SSOC) near Tokyo provides communications support and interface to the JPL Network Operations Control Center for DSN support. Orbit determination is provided by the Tsukuba Space Center of the Japanese National Space Development Agency (NASDA).

Tracking and Data Acquisition

The prime tracking and data acquisition station for Astro-D will be the station at Kagoshima (131° E. Long. and 31° N. Lat.) which will be in contact with the spacecraft for 5 consecutive orbits per day. The orbit ground tracks, on a Mercator projection map, are indicated by Figure 12. Five consecutive-orbit contacts are possible with Astro-D because of the relatively high orbit altitude (550 km) and the fact that orbit inclination equals the latitude of the ground station.

Contact duration is up to about 12 minutes, during which commands will be relayed to the spacecraft, and real-time and playback telemetry data will be received. Because the contact times are short, spacecraft operations are primarily based on time tagged commands.

The Tsukaba Space Center receives tracking data acquired by the Japanese space tracking network which consists of four stations located at Tanegashima, Okinawa, Katsuura and Uchinoura. The ISAS will provide pre launch orbital elements (state vectors) to JPL for each DSN station data acquisition sufficiently in advance of the launch date and will continue to provide updated state vectors to JPL throughout the mission, as applicable. The DSN stations involved are Goldstone, Madrid and Canberra. These stations are only used for data acquisition.

NASA Role

NASA is responsible for providing pre-mission test support and mission support. The transponder and telemetry data system for Astro-D are the same as those used on earlier ISAS spacecraft. Some of these on-orbit, operating spacecraft were, therefore, used in the testing for Astro-D.

The DSN will provide data capture support for a primary Astro-D mission of two years duration with a possible extension of another two years. Four DSN station contacts per day will be provided during the primary mission. Two contacts per day will be provided during the mission extension.

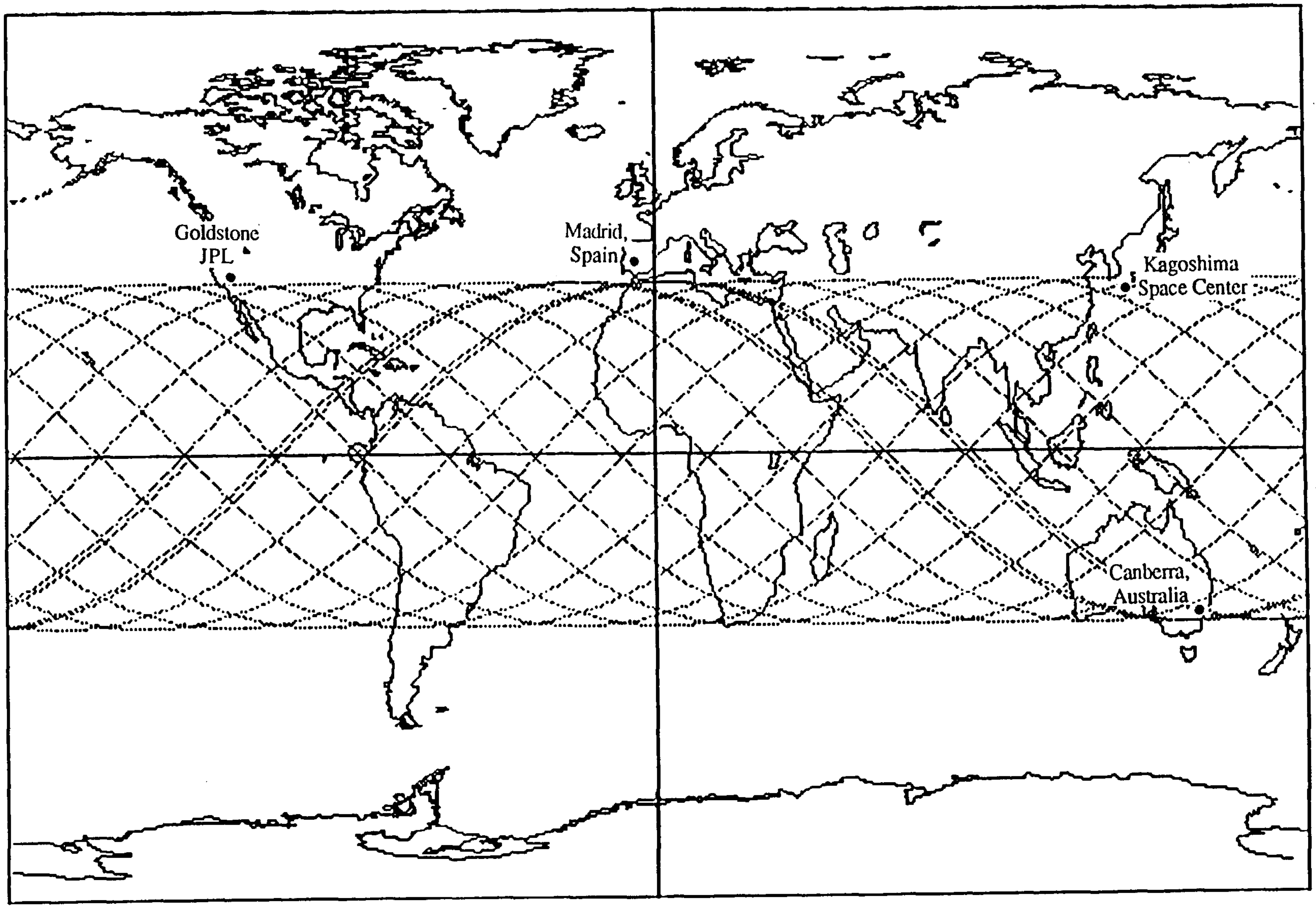


Figure 12. Astro-D Orbit Ground Tracks on a Mercator Projection Map

NASA Communications (NASCOM) support will consist of one voice circuit between JPL and each DSN station for Astro-D operations coordination and one 56 kbps data circuit from JPL to the ISAS SSOC in Japan. Astro-D telemetry data from the DSN 26-meter subnet will be transmitted non-realtime to the ISAS SSOC via the existing data line utilized by Solar-A (YOHKOH) and other cooperative projects. The data shall be frame synchronized using four frames per block (1024 bits per frames).

Data Management

A diagram showing the Astro-D downlink data flow and its distribution to the science community is provided by Figure 13. Astro-D's bubble memory tape recorder will transmit science information to both the ISAS Kagashima ground station and the NASA DSN stations. DSN data are channeled through JPL. The ISAS Astro-D Science Center makes a quick-look analysis to verify health and then archives the data for later, more detailed studies.

Data are transferred from Sagamihara to the U. S. Astro-D Science Center at NASA's Goddard Space Flight Center (GSFC). These data are distributed to the U. S. Guest Investigators and instrument teams. After a period of 1-2 years, the data are transferred to the High Energy Astrophysics Science Archive Research Center (HEASARC) at GSFC for release to the scientific community at large.

The Japanese Science Center fulfills similar distribution functions for the Japanese investigators.

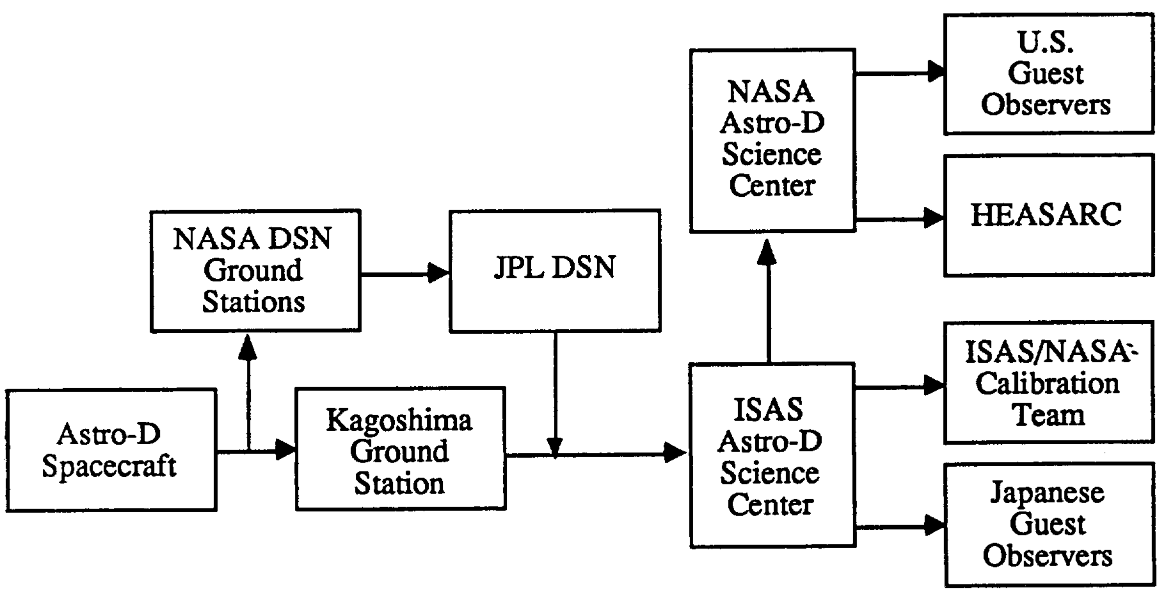


Figure 13. Data Flow Diagram

MISSION MANAGEMENT

The Astro-D program is managed by the Japanese Institute of Space and Astronautical Science (ISAS). NASA is responsible for providing the four X-ray mirrors and two of the four detectors, data capture through the Deep Space Network (DSN), and support of the U. S. Investigation Team.

Within NASA, the Office of Space Science and Applications (OSSA) at NASA Headquarters is responsible for the overall direction and evaluation of NASA's role in the Astro-D mission. The Associate Administrator for OSSA has assigned Headquarters responsibility to the Director of the Astrophysics Division. This Division provides program management for the development phase and the mission operations and data analysis phase of the program. The Goddard Space Flight Center (GSFC) has been assigned responsibility for project management within NASA. Within GSFC, Astro-D management is carried out by the International Projects Manager of the Flight Projects Directorate, and is led by a designated Project Manager and Deputy Project Manager. An Astro-D Project Scientist is assigned from the GSFC Space Sciences Directorate. The four X-ray mirrors are provided by GSFC, while the two U. S.-built detectors are provided to NASA by the Massachusetts Institute of Technology (MIT). The Office of Space Operations, NASA Headquarters and the Jet Propulsion Laboratory (JPL) are responsible for the U. S. tracking and data capture support.

The responsible organizations and personnel are:

ISAS (Japan)

Prof. Yasuo Tanaka	Project Manager/Project Scientist for Astro-D
Prof. Hajime Inoue	Deputy Project Manager for Astro-D

NASA Headquarters, Office of Space Science and Applications

Dr. Lennard A. Fisk	Associate Administrator for Space Science and Applications
Alphonso V. Diaz	Deputy Associate Administrator for Space Science and Applications
Dr. George P. Newton	Acting Director, Astrophysics Division
John A. Lintott	Astro-D Program Manager
Dr. Alan N. Bunner	Astro-D Program Scientist

NASA Office of Space Communications

Charles T. Force	Associate Administrator for Space Communications

NASA Goddard Space Flight Center

Dr. John M. Klineberg	Director
Vernon J. Weyers	Director of Flight Projects
Jerre B. Hartman	Project Manager for Astro-D
Dr. Stephen S. Holt	Project Scientist for Astro-D
Dr. Peter J. Serlemitsos	Principal Investigator for Astro-D Mirrors

Jet Propulsion Laboratory

Dr. Edward C. Stone	Director, Jet Propulsion Laboratory
Norman R. Haynes	Assistant Laboratory Director for TDA
Raymond J. Amorose	TDA Mission Support & DSN Operations
Joseph Goodwin	DSN Tracking and Data Systems Manager for Astro-D

Massachusetts Institute of Technology

Dr. George R. Ricker	Principal Investigator for CCD Detectors

ASTRO-D PROJECT COST

ESTIMATED U. S. COST FOR ASTRO-D:

• Astro-D Development	\$11.4 M